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PHYSICAL ACTIVITY IN SWEDISH AND CHINESE YOUNG CHILDREN AND THEIR PARENTS

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PHYSICAL ACTIVITY IN SWEDISH AND CHINESE YOUNG CHILDREN AND THEIR PARENTS

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ABSTRACT

Physical activity is believed to affect health, already in childhood. Studies of physical activity in children under the age of three are, however, sparse. The overall aim of this thesis was to explore physical activity and its possible correlates in Swedish and Chinese children, aged one and two, at high and low risk for obesity. Physical activity levels and patterns among parents in Sweden and China were also examined.

Study I was a calibration study where children, 15 to 36 months old, were recruited from four preschools in Stockholm, Sweden. Physical activity data, measured with accelerometry, was compared against data from Children's Activity Rating Scale (CARS). Accelerometer count thresholds for sedentary, low- and high-intensity physical activity was derived (n=26) and cross-validated (n=12).

Studies II-IV were explorative cross-sectional studies where physical activity levels, patterns and correlates were examined among one- (*Study III*) and two-year-old children (*Studies II and IV*), participating in Early STOPP (Stockholm Obesity Prevention Project) *Sweden* (*Studies II and IV*) and *China* (*Studies III and IV*). Children and their parents wore an accelerometer for seven days to assess average physical activity (counts per minute) and time spent at different intensities. Differences between weekdays and weekend days were examined as were correlations with sex, body mass index (BMI), motor skills and family-related factors.

The intensity thresholds developed in *Study I* were found valid for two-year-old children. Swedish two-year-old children had an intermittent activity pattern with short bursts of high intensity physical activity (*Study II*). At this age, Swedish children accumulated 2989 (SD 702) counts per minute and spent 57%, 34% and 9% of the day respectively in sedentary, at low- and high-intensity. Chinese children accumulated 1997 (SD 899) counts per minutes and spent 70% of the day being sedentary, 25% at low- and 5% at high-intensity (*Study IV*). Swedish children varied their activity levels more over the day, compared with their Chinese counterparts (*Study IV*). In both countries, activity levels were similar on weekdays and weekend days. No association was found between physical activity and sex, BMI, motor skills or any family-related factor at age one (*Study III*) or two, except for a positive association between fathers' and boys' physical activity at age two in Sweden ($p<0.05$, $r=0.49$ on weekdays and $r=0.37$ on weekends) (*Study IV*). Swedish parents were more active than their Chinese counterparts ($p<0.05$), and mothers were more active than fathers in both countries ($p<0.05$) (*Study IV*).

In conclusion, physical activity levels and patterns in young children and their parents differ substantially between countries. This indicates that physical activity can be markedly modified by environmental or socio-cultural factors already at two years of age.

SAMMANFATTNING

Fysisk aktivitet tros påverka hälsan redan i barndomen. Kunskapen om fysisk aktivitet hos barn under tre år är dock begränsad. Det övergripande syftet med denna avhandling var att undersöka fysisk aktivitet hos svenska och kinesiska barn i ett- och tvåårs åldern, med hög, respektive låg risk för fetma. Syftet var också att undersöka faktorer med möjlig koppling till fysisk aktivitet i denna ålder. Fysisk aktivitetsnivå och aktivitetsmönster bland svenska och kinesiska föräldrar undersöktes också.

Studie I var en kalibreringsstudie där barn mellan 15 och 36 månader gamla rekryterades från fyra förskolor i Stockholm, Sverige. Fysisk aktivitet, mätt med accelerometri, jämfördes med data från Children's Activity Rating Scale (CARS). Tröskelvärden för stillasittande, låg och hög intensitet togs fram ($n=26$) och korsvaliderades ($n=12$).

För *Studie II-IV* användades data från Early STOPP (Stockholm Obesity Prevention Project) Sverige (*Studie II and IV*) och Kina (*Studie III and IV*). Dessa var utforskande tvärsnittsstudier där fysisk aktivitetsnivå, aktivitetsmönster och faktorer med möjlig betydelse för fysisk aktivitet undersöktes hos barn i ett- (*Studie III*) och tvåårsåldern (*Studie II and IV*). Barnen och deras föräldrar bar en accelerometer under sju dygn för att mäta genomsnittlig fysisk aktivitet (counts per minut) och tid spenderad i olika intensitetsnivåer. Skillnader mellan veckodagar och helgdagar undersöktes, liksom samband med kön, BMI, motorisk utveckling och familjerelaterade faktorer.

Tröskelvärdena framtagna i *Studie I* visade sig vara valida för barn i tvåårsåldern. Svenska tvååringar hade ett oregelbundet aktivitetsmönster med korta sekvenser av hög intensitet (*Studie II*). Vid denna ålder ackumulerade Svenska barn 2989 (SD 702) counts per minut och spenderade 57% av dagen stillasittande, 34% i lågintensiv och 9% i högintensiv aktivitet. Kinesiska barn ackumulerade 1997 (SD 899) counts per minut och spenderade 70% av dagen stillasittande, 25% i lågintensiv och 5% i högintensiv aktivitet (*Studie IV*). Svenska barn varierade sina aktivitetsnivåer mer över dagen, jämfört med Kinesiska barn (*Studie IV*). I båda länderna var aktivitetsnivåerna likartade under veckodagar och helgdagar. Inget samband mellan fysisk aktivitet och kön, BMI, motorisk utveckling eller någon familjerelaterad faktor fanns vid ett (*Studie III*) eller två års ålder, förutom ett positivt samband mellan svenska fäders och söners aktivitetsnivåer vid två års ålder ($p<0.05$, $r=0.49$ på veckodagar och $r=0.37$ på helgdagar) (*Studie IV*). Svenska föräldrar var mer aktiva än Kinesiska föräldrar ($p<0.05$) och i båda länderna var mödrar mer aktiva än fäder ($p<0.05$) (*Studie IV*).

Sammanfattningsvis skiljer sig fysisk aktivitetsnivå och aktivitetsmönster hos småbarn och deras föräldrar signifikant mellan länder. Detta tyder på att fysisk aktivitet kan påverkas avsevärt av omgivningsmässiga och socio-kulturella faktorer, redan vid två års ålder.

LIST OF SCIENTIFIC PAPERS

- I. **Calibration and cross-validation of a wrist-worn Actigraph GT3X+ in young preschoolers.**
E. Johansson, U. Ekelund, H. Nero, C. Marcus, M. Hagströmer.
Pediatric Obesity, 2015, 10, 1-6
- II. **Objectively measured physical activity in two-year-old children - levels, patterns and correlates.**
E. Johansson, M. Hagströmer, V. Svensson, A. Ek, M. Forssén, H. Nero, C. Marcus.
IJBNPA, 2015, 12, 3
- III. **Physical activity levels in Chinese one-year-old children and their parents, an Early STOPP China study.**
H. Mei*, E. Johansson*, M. Hagströmer, Y. Xiong, L. Zhang, J. Zhang**, C. Marcus**.
Manuscript
- IV. **Physical activity in two-year-old children – An Early STOPP Sweden – China comparison study.**
E. Johansson*, H. Mei*, L. Xiu, V. Svensson, J. Zhang**, C. Marcus**, M. Hagströmer**.
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LIST OF ABBREVIATIONS

| | |
|---------|--|
| AUC | Area under the curve |
| BMI | Body mass index |
| BMI SDS | Body mass index standard deviation score |
| CARS | Children's activity rating scale |
| CI | Confidence Interval |
| CPM | Counts per minute |
| IOTF | International obesity task force |
| IQ | Intelligence quotient |
| MET | Metabolic equivalent |
| NOS | Neurological optimality score |
| ROC | Receiver operating characteristic |
| SD | Standard deviation |
| VM | Vector magnitude |
| WHO | World health organization |

1 INTRODUCTION

Physical activity has always been one of my biggest interests and I have, for as long as I can remember, been fascinated by the human body and how it functions. Ever since I started my training to become a physiotherapist, I, unlike my study-peers, wanted to become a researcher. I was thrilled when I was involved in the Early Stockholm Obesity Prevention Project (Early STOPP) in 2010 and got the opportunity to do my PhD within the physical activity area.

One year earlier, in 2009, Early STOPP was initiated to explore if childhood obesity could be prevented in a risk-group of children with overweight or obese parents, and to study factors related with childhood obesity. The study is still ongoing and children at increased risk for becoming obese, based on parental relative weight, are followed from age one to age six. Their parents are also followed, enabling exploration of their habits and influence on their children. Early STOPP has two geographical sites, one in Stockholm, Sweden and one in Wuhan, China. Identical protocols are followed, enabling interesting comparisons between the countries.

Obesity is a topic that is engaging. New “methods” to lose weight and prevent weight gain are frequently highlighted on the headlines to sell single copies. It is a common presumption that lack of physical activity is the major contributor to development of obesity. Research has, however, shown that physical activity alone cannot cure obesity and its role in prevention of obesity is questioned [1]. Nevertheless, physical activity is essential for preventing diseases linked with obesity in adults, such as cardiovascular diseases, cancer, chronic respiratory diseases and diabetes [2]. It also reduces the risk of premature death in both normal-weight and obese individuals [2, 3].

The development of methods to measure physical activity has enlarged the understanding of physical activity behaviors in various populations. Nevertheless, there are still unexplored fields within the physical activity area. Studies of toddlers (children 1-2.9 years of age) are rare as well as studies performed in countries other than Europe, the United States and Australia. It is not known how active toddlers are and how they vary their activity levels over a week and over a day. It is also not known what factors can explain variations in their activity levels. Physical activity levels and patterns among parents with toddlers and the impact of parental related factors on their child’s activity are also lacking. This aim of this thesis is to explore this unknown field of research and to answer some of the unanswered questions.

2 BACKGROUND

2.1 PHYSICAL ACTIVITY AND MOTOR SKILLS

Physical activity is defined as "any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level" [4]. Bodily movements can be described in terms related to the actual behavior, in which frequency (number of physical activity events in a specific period), duration (amount of time) and intensity (physiological effort) are key aspects and make up the total dose of activity. The type of activity can also be described: running, swimming, standing, sitting, or walking, for example. Since energy expenditure is the result of movements, it can be used as an indirect description of physical activity [5]. These different approaches to describe bodily movements are explained below. Motor skills, which provides the basis for physical literacy [6], is described later in this section.

2.1.1 Physical activity and sedentary behaviors

Levels and patterns are often used to describe physical activity as a behavior, as these outcomes are highly related to health. *Levels* are frequently defined as total or average activity over a day or other time period, determined by the frequency, duration and intensity of activities performed during that time frame. The levels can also be described as proportions of time (time units or percent) spent at various intensity levels. Physical activity *patterns* are described by variations in frequency, duration and intensity over a year, a week, a day, or any other time period.

Intensity is the most difficult component of physical activity to measure [5], and can be described in absolute or relative terms. Measures used to describe absolute intensity are, for example, velocity or watt, which specify how vigorous the activity is regardless of the individual capacity. A brisk walk can, however, be perceived as moderate for one individual but vigorous for another. The effort required for the activity is, thus, related to the capability of the individual performing the activity. When the maximal capacity of the individual is taken into account, the term relative intensity is used. It is often described as percent of maximal heart rate or percent of maximal oxygen consumption. Intensity levels are usually graded from inactive to very high or very vigorous; the more intense the activity is, the more energy is expended. Moderate intensity refers to when the activity is so strenuous that the frequency of breathing and heartrate increases. Children are growing and maturing and differ physically from adults, especially before puberty. They have a limited tolerance for vigorous activity and a poorer economy and efficiency of movement, as compared with adults [7], making it difficult to define intensity levels. This is one aspect that makes assessment of physical activity in children challenging.

Inactivity refers to a condition when energy expenditure is very low, close to levels of complete rest [8]. The term "inactive" is frequently used in the literature, however, in the sense of not reaching the current physical activity recommendations. The term "sedentary

behavior” is therefore recommended to be used for activity levels that are very low. The definition of sedentary, from the Latins Sedere – ‘to sit’, is under debate [8]. Some argue that the definition should include a statement about body position (sitting or reclining), while others state that body position is irrelevant given that the body is expending very little energy, thus also including standing without moving [8, 9]. The view of sedentary behavior as a separate construct with its own correlates and health consequences has emerged in recent years, but activity and sedentary behavior are related: if one decreases, the other increases. During a normal day we are both active at different intensities, and sedentary to some extent. Not all studies on sedentary behavior have taken levels of physical activity into account, which is why the association between sedentary behavior and health risks is unclear.

2.1.2 Energy expenditure as a measure of physical activity

By definition, energy expenditure is the consequence of bodily movements and can thus be measured as a proxy for physical activity levels. The concept of metabolic equivalent (MET) values was developed to describe the energy cost of certain activities in terms of absolute intensity [10]. Based on the individual’s energy expenditure while resting, the energy expenditure of the specific activity is multiplied by that value. A MET value of 1 represents complete rest, ≤ 1.5 METs represents inactivity/sedentary, 1.6-2.9 represents low/light intensity, 3-6 corresponds to moderate intensity, and a value of >6 to high/vigorous intensity. The MET concept is an absolute measure of intensity, meaning that it does not take individual variations in maximal capacity into account. The MET concept was originally developed for adults [10]; a compilation for children is available [11], but it is not adapted for toddlers or preschoolers. Nevertheless, many questionnaires and observational methods used to measure physical activity in children are based on the MET concept [5].

2.1.3 Motor skills development

Motor skills can be defined as "the ability to activate the correct pattern of muscles to accomplish a task" [12]. A distinction is often made between fine motor skills - small movements such as painting and assembling a puzzle - and gross motor skills, which constitutes of larger movements such as jumping and kicking. Another frequently used term is “fundamental motor skills”, which refers to movements that involve various body parts crucial for physical activity [6].

During the first two years of life, motor control increases dramatically. Newborn children are already making bodily movements, primarily waving arms and kicking legs. Later, first-year infants rock back and forth, sway, or bounce up and down when placed into a seated position. By the end of the first year most children are crawling on their hands and knees. A few months later, usually between eleven and 14 months, the child is able to stand unassisted and walk short distances. The walk is still unstable, which is why many children still choose to crawl. Walking becomes more and more stable, and the distance between the feet narrows. By two years of age the gait is increasingly rhythmical, providing greater opportunity to be physically active [13]. In two-year-old children, movements consist primarily of play [14]

and the mastery of fundamental motor skills are increasing [15]. Studies have shown that motor skill proficiency in early life can predict motor skills later in life [16-18].

Early development of fundamental motor skills has been suggested to increase opportunities to be physically active and thus prevent excessive weight gain through increased energy expenditure. Excessive weight could also hinder movement and thereby delay motor skill development in children. Cross-sectional studies have found associations between obesity and low motor skill proficiency [19-23]. However, a large longitudinal study on over 20,000 Danish children did not find that higher birth weight or body mass index (BMI) at five months of age was associated with lack of achievement of motor milestones (sitting up and walking unassisted). Also, late achievement of these motor milestones did not predict BMI at age seven [24]. Taken together, the association between motor skill development and overweight or obesity is unclear. Different methods of assessing adiposity are one reason for the inconsistent findings. The amount of body fat, in comparison with BMI, has been found to correlate more strongly with motor skills [25, 26]. In addition, the methods for assessing motor skills vary between studies and are possibly not be sensitive enough.

2.1.3.1 Assessment of motor skills

Most methods for assessing motor skills in healthy infants and toddlers rely on parental reports of achievements of motor milestones such as sitting and walking unassisted [26]. Parental report of motor milestones is a rather crude measure but it has been found to be reasonably accurate [27, 28]. The World Health Organization (WHO) has developed age-range standards for healthy children reaching these motor milestones, based on samples of children in Ghana, India, Norway, Oman and the United States [29]. Examples of other methods for assessing motor skills are “The Motor Scale of the Bayley Scales of Infant Development” [30, 31], and the “Peabody Developmental Motor Scales-2” [32] but these techniques are primarily used in clinics to detect and diagnose children with disabilities. From three years of age, the “Movement ABC” [33] is a reliable assessment technique frequently used in both clinics and in research [34, 35].

Most examination techniques for infants and toddlers are aimed at detecting abnormalities, though these tests are probably not sensitive enough to detect minor delays in motor skill development among healthy children. In 1980, the concept of “optimality” was introduced [36]. An optimal condition is more restricted and more narrowly defined than a normal condition, which is why the optimality concept likely is more suitable for detecting minor delays in healthy children. The “neurological examination technique for toddler-age” according to Hempel [37] is an assessment method based on the optimality concept developed for children between 1.5 and four years of age.

2.1.4 Physical activity and health

2.1.4.1 Adults

Physical activity is essential for preventing non-communicable diseases (cardiovascular diseases, cancer, chronic respiratory diseases and diabetes) and can substantially reduce mortality risks in normal and obese individuals [2, 3]. Too little physical activity increases the risk of premature death by 20-30% and causes over 3 million deaths globally each year [38]. The prevalence of non-communicable diseases is increasing worldwide and most rapidly in Asia [39]. In adults, physical activity has positive effects on cardiorespiratory-, metabolic-, bone- [40, 41] and mental health [40]. Physical activity recommendations are based on a dose-response relationship between physical activity and health. The more active – the better effect, but the highest health benefit is gained for an individual who goes from being very inactive to being moderately active.

WHO recommend adults aged 18-64, regardless of sex, race, ethnicity or income level - to be physically active for at least 150 minutes per week at a moderate level of intensity, or perform at least 75 minutes of vigorous aerobic physical activity throughout the week or an equivalent combination of moderate and vigorous activity. The activity should be performed in sessions of at least 10 minutes duration. Muscle-strengthening exercises involving major muscle groups should also be performed two or more days a week. Additional activity leads to additional health benefits [38]. National guidelines, similar to the recommendations from WHO, are available in both Sweden [42] and China [43].

2.1.4.2 Children

Aerobic capacity, muscle strength, motor skills and coordination develop over time in childhood, influencing the effects of physical activity on health. Higher levels of physical activity in preschool children have been associated with favorable health outcomes. However, the minimal and optimal amount (frequency, duration and intensity) of physical activity that produces these positive effects is unclear [44]. Difficulties related to measurement of child activity, and the fact that it takes time for unhealthy behaviors to influence chronic disease, are two reasons for the lack of knowledge.

Only a few studies have been performed in children under five years of age; almost all of them have been conducted in western contexts and rely on parental reporting of child physical activity [44]. Taken together, physical activity in infancy and toddlerhood has been associated with improved motor skill and cognitive development. There is moderate evidence that higher levels of physical activity are associated with bone and skeletal health in toddlers; again these results rely on very few studies. There is a pronounced need for more studies on children under three years of age, as well as studies of the effects on health among children in middle- and low-income countries [45].

The WHO recommend children five years of age and older to be at least moderately active for 60 minutes per day [38]. No global recommendations for children under five years of age

exist; national guidelines, however, have been developed in some countries. The United States recommend children to be active for at least 120 minutes per day [46], while Australia and the United Kingdom recommend at least 180 minutes per day [47, 48].

In Sweden, children under five years of age should be encouraged to be active; physical activity should be facilitated by providing interesting, joyful and safe environments that encourage the motor skill development [49]. No information about duration and intensity has been provided due to the low number of studies and inconsistent findings in the available studies. There are no recommendations for physical activity in Chinese toddlers, but it is recommended for preschool children to be physically active outdoors for at least two hours per day [50].



2.1.5 Physical activity levels and patterns in toddlers

Most studies of physical activity levels and patterns in preschool children have been conducted in the United States, Europe and Australia [44, 51, 52]. Few studies have been conducted in low- and middle-income countries and studies of children under three years of age are sparse [53, 54], especially where physical activity has been measured objectively. It is commonly assumed that young children are habitually and equally active [55], but this has not been confirmed with objective methods for toddlers. Physical activity in this age group is a research area that needs exploration [56].

2.1.5.1 Levels

In one review, summarizing the results from studies of children 0-4 years of age, it was concluded that children of that age are physically active for an average of 130 minutes per day, at least at a low level of intensity [44]. Proportions of time spent at different intensity levels have been found to vary substantially in different studies: 34-94% sedentary, 4-33% low-intensity, and 2-41% at least moderate intensity [54, 57]. However, these results are primarily based on data from children 3-5 years of age and physical activity have most often been assessed subjectively. A study of physical activity among 295 Australian children aged 19 months, assessed with objective methods, showed that they engaged in a daily average of 184 minutes of low-intensity and 47 minutes at moderate or higher levels. Over 90% met the Australian recommendations of at least 180 minutes of activity per day [51]. The large differences between studies of time spent at various intensities are probably due to differences in the definition of intensity levels.

2.1.5.2 Patterns

School-age children are more active during weekdays than on weekends [58-60]. Studies of younger children are sparse, but differences across days have been found as early as four years of age [61-63]. Two studies of hourly patterns of physical activity in toddlers were found in the literature. These studies, on Australian 19-month-olds and American three-year-olds, found that children were more active in mid-morning and mid-afternoon than at other times of the day [14, 51]. This pattern - a decrease in activity during early afternoons and an increase in the late afternoon - is in line with studies on Australian preschool children [61, 62]. Young children are often assumed to have an intermittent activity pattern with short bursts of activity and sedentary time [64], but this has not been confirmed using objective methods in toddlers in low- and middle-income countries.

2.1.6 Possible correlates of physical activity in toddlers

The socio-ecological framework was developed in year 2000 to structure the study of possible correlates of physical activity in children [65]. In this model, a number of factors from biological to environmental aspects are included to explain physical activity behavior. Possible correlates of physical activity has been identified and categorized into five domains (Biological and demographic; Psychological, cognitive and emotional; Behavioral attributes

and skills; Social and cultural and Physical environmental). Examples of correlates within these domains are presented in Table 1. Some of the possible correlates are modifiable, e.g. time spent in front of TV or outdoors, while others, like sex and age, obviously is not.

Table 1. Domains of the socio-ecological framework by Sallis (2000) and examples of variables within each domain.

| Domains | Biological and demographic | Psychological, cognitive and emotional | Behavioral attributes and skills | Social and cultural | Physical environmental |
|--------------------------------------|---|---|---|--|---|
| Possible correlates, examples | Sex, age, body composition, socio-economic status, motor skills, parental relative weight | IQ, personality | Television viewing, participation in sports | Parental physical activity, parental support | Time spent outdoors, day care, neighborhood safety, weather conditions, weekdays vs weekends, time of day |

As with levels and patterns, the body of research on correlates of physical activity is sparse among children under five years of age in general and toddlers in particular. Studies that include toddlers in developing countries are even rarer. For toddlers, family-related factors (e.g. parental features, type of child care, and presence of siblings) are hypothesized to be of importance. The possible correlates described below are structured in relation to the socio-ecological framework [65].

2.1.6.1 Biological and demographic correlates

The influence of genetics is a growing research area and there is evidence that biological processes do regulate physical activity [45]. Genetics probably play a role in a toddler's physical activity on an individual level, but environmental factors are also of major importance. It has been argued that genetics contribute to stability in physical activity and that environmental factors contribute to change [66].

Boys have been consistently shown to be more physically active than girls from four years of age [45, 52, 57, 65], but it is not yet clear whether these differences can be seen as early as age two. Socio-economic status [63, 67] the presence of siblings [67-70] and parental relative weight [52] do not seem to be related to sedentary time or physical activity in preschool children.

The cross-sectional association between physical activity and body composition remains unclear, but most studies of preschoolers [52, 65, 71-73] and infants [13] have failed to find such an association. A small study on Swedish children aged nine and 14 months found that children with lower body fat were more active than those with higher body fat [74]. Recent studies have suggested that there is an inverse relationship between body fat and physical activity. A longitudinal study found that body fat at age seven predicted physical activity at age ten, but physical activity at age seven was not associated with body fat at age ten [75].

Motor skills are associated with physical activity in school-age children [6, 76] and possibly from the age of four years as well [44, 77, 78]. The casual direction of this association is not clear, but motor skills in childhood have been found to predict physical activity levels in adolescents [18].

2.1.6.2 Psychological, cognitive and emotional correlates

Physical activity has been associated with self-esteem and cognition in school-aged children [79]. Too few studies of children under three have been performed to examine these associations, which is why no conclusions can be drawn [52].

2.1.6.3 Behavioral attributes and skills

TV-viewing is the most commonly studied variable among preschool children within this domain. A negative association between TV-viewing and physical activity have been found in some studies but an equal number of studies have failed to find such an association [52]. Most of the studies rely on parental reporting of TV-time and includes only children older than three.

2.1.6.4 Social and cultural correlates

The association between parent's and children's physical activity remains unclear. In some studies such an association has been found in children under seven years of age [52, 80], while others have failed to find such an association [65, 69, 71, 81]. Paternal activity, in comparison with maternal activity, have been found more strongly associated with child physical activity [82]. Parental support has been found to be a correlate in school-age children [65, 73, 83], but not in preschoolers [52]. Restricting infants and toddlers to strollers and small play spaces affects their ability to be physically active [15] but it is not clear if it affects their total activity levels.

2.1.6.5 Physical environmental correlates

Preschool attendance [52, 63, 68] and time spent outdoors [52, 65, 67, 84-86] have been positively associated with physical activity in children. How the environment is perceived seems to be an important factor, especially in low- and middle-income countries [45]. Parental concerns around the safety of the neighborhood, work demands from parents that limit time for leisure activities, a neighborhood designed in a way that discourages walking, are other environmental correlates that affect preschool children's physical activity [15].

One reason for this knowledge gap concerning levels, patterns and correlates of physical activity in preschool children in general - and specifically toddlers - is the problems related to measuring physical activity. The assessment of physical activity is discussed in the next section.

2.1.7 Assessment of physical activity

Assessment of physical activity, especially in toddlers, is challenging. Development of accurate methods for measuring physical activity in children has been singled out as an important area for research [56]. Either actual movements (behavior) or the consequence of the movements (energy expenditure) can be assessed. Examples of methods for measuring energy expenditure are indirect calorimetry, doubly labeled water and heart rate monitoring. Most often, levels and patterns of physical activity are measured when assessing the behavior aspect; this can be performed by using subjective or objective methods.

2.1.7.1 Assessment of levels and patterns

Among subjective methods, questionnaires are most commonly used. Questionnaires are cost-effective, cause a low burden on participants and can easily be distributed to many participants [87]. The validity of questionnaires in assessing physical activity is low, however, due to recall bias, social desirability and misinterpretation [88]. Toddlers cannot remember and report their own activity but questionnaires filled in by parents are often used to assess physical activity in preschool children, which is difficult. Motion sensors (e.g. pedometers and accelerometers) and direct observation are examples of objective methods. These methods have the advantage of not relying on self-reported or parental reported data and have been suggested as useful for preschool children and toddlers in particular [64]. In this thesis, accelerometers - a type of motion sensors - and direct observation were used to assess physical activity; these methods are described in more detail below.

2.1.7.2 Motion sensors

There are different types of motion sensors, but accelerometers are the most widely used in research [89]. Accelerometers measure physical activity through recording accelerations caused by bodily movements. They have been found to validly measure physical activity in adults [90] and in preschool children [91] and have been found feasible for use with toddlers [91]. They have some disadvantages: weight-bearing activities, climbing and bicycling are underestimated. If an infant is carried, the accelerometer will register that as child activity; child activity will thus be overestimated [92]. Nevertheless, accelerometers are probably the most useful tools for assessing physical activity over extended periods of time. Most often, data is collected for seven days but data can be collected for as long as several weeks, depending on how frequently data are sampled. Since accelerometers can sample data many times per second, they are particularly well suited to capture the short bursts of activity characteristic of toddlers and preschool children [64]. Frequency, duration and intensity can be determined, which is why the total or average amount of activity and proportions of time at different intensity levels as well as physical activity patterns, can be assessed. Many

monitors can assess body position and can produce a measure of steps taken. Some monitors are also designed to measure sleep.



The accelerometer Actigraph GT3X+ worn on the wrist

Newer accelerometers are small, lightweight and water-resistant. They can be worn on different areas of the body such as the hip, the wrist or the ankle. Wrist placement can increase compliance in children and is perceived as more comfortable compared to hip placement for recordings over several days [58, 93, 94], but it has lower validity compared with hip placement [95]. Older accelerometers captured only vertical acceleration, while newer monitors are most often tri-axial. The vector magnitude (VM) is a measure of the three axes combined, defined as $\sqrt{(x^2 + y^2 + z^2)}$. Raw data is compiled over a certain epoch length, most often 60 seconds for adults. For children a shorter epoch length has been suggested to more accurately capture their intermittent activity patterns [64], preferable 5 seconds [96]. Output is most often what is known as a “counts-value”, which is not comparable across different types of monitors or between monitors worn on different placement sites [97]. Body size is another factor that affects the counts-value.

2.1.7.3 Calibration of accelerometer output

Since the counts-value is not a defined unit, the accelerometer output needs to be calibrated into something more physiologically meaningful, such as intensity categories, energy expenditure, or activity type [89]. To calibrate a monitor, data is collected from several individuals wearing monitors while using a criterion method or “gold standard” against which the accelerometer data is compared. Direct observation is the criterion method most commonly used to calibrate accelerometer data into intensity categories in young preschoolers [98], and has been proposed as the “gold standard” in toddlers and preschool children [64].

2.1.7.4 Direct observation

Various observational techniques have been developed for children, most of which rely on an observer who scores the intensity of the child’s activity at a given time interval, for example

every five seconds or every minute, over a certain length of time. Considerable time is required and the method relies on a subjective component to some extent through its dependence on the observer's assessment. Children's Activity Rating Scale (CARS) is the most commonly used observational method in preschool children [99] and has been used in the original or modified versions as the criterion method in many studies where accelerometer data was calibrated [100-103].

2.2 OVERWEIGHT AND OBESITY

The number of people around the globe suffering from overweight or obesity has recently become greater than that of people suffering from famine [104]. Obesity is no longer considered a disease only affecting high-income countries; low- and middle-income countries are also affected. The health risks associated with being obese affects people in Asia even more profoundly, due to differences in body composition and in the location of body fat compared with people of western origin [105].

2.2.1 Definitions

Overweight and obesity are most often defined in terms of BMI, which is the most commonly used measure of body composition in clinic and research. BMI is calculated by dividing the body weight (kg) by the square of the height (m), i.e. kg/m^2 . In adults, overweight and obesity are defined respectively as BMI 25-29.9 kg/m^2 and $\geq 30 \text{ kg/m}^2$ [106]. In some populations, mainly in Asia, the cut-offs are lower due to differences in body-composition compared with individuals in western countries. In China, overweight and obesity are defined as BMI 24-27.9 kg/m^2 and $\geq 28 \text{ kg/m}^2$, since these limits have been found to increase the risk of mortality [107].

Body composition changes naturally as a child matures, which is why the definition of a healthy BMI in children varies by age and sex. BMI in children must be compared against national or international references, standardized by age and sex, to enable categorization. One commonly used reference is the International Obesity Task Force (IOTF) standard, which is based on data from children in the United States, the United Kingdom, Hong Kong, the Netherlands, Singapore and Brazil [108] and has been recommended for international use for children from two years of age. Rough BMI-values cannot be compared across sexes and ages. Based on a reference population, a BMI standard deviation score (BMI SDS), which takes sex and age into account, can be used [109].

2.2.2 Prevalence

The prevalence of overweight and obesity among children has increased radically in the past few decades. WHO estimates that 42 million children under five years of age are overweight; most of them live in developing countries [110]. It is estimated that about 15% of European two-year-olds are overweight or obese [111]. Since 1980, the prevalence of childhood overweight and obesity has risen dramatically in Sweden [112]. The current prevalence of overweight and obesity among preschool children in Sweden is not known but in Stockholm,

the capital of Sweden, 9% of children are overweight and 2% obese at age four [113]. There are indications that the prevalence of childhood overweight and obesity in some European countries – Sweden for example - has fallen, at least among some subgroups, but it still remains a major public health concern and there are large regional and socio-economic differences [114, 115]. In developing countries, such as China, the prevalence is still rising dramatically, especially among male toddlers living in urban areas [116]. The prevalence of overweight and obesity among two-year-old children in one of the largest cities in China are 27% and 11%, respectively [117].

2.2.3 Development of obesity in children

The development of childhood obesity is not fully understood but both genetic and environmental factors play a role [118]. Despite the genetic influence, keeping a stable weight requires energy balance – that is the amount of energy consumed is equal to the amount expended; a positive energy balance over time will lead to overweight. It is well known that energy intake is related to BMI in children [119, 120]. The role of physical activity is less clear but it is possible that increased activity and decreased sedentary behavior can prevent weight gain to some extent [121, 122] and a low level of total activity has been found associated with development of overweight and obesity in children and adolescents [123].

In many developing countries, such as China, traditional beliefs have not changed as rapidly as socio-economic development. Due to earlier poverty and starvation, adiposity is seen as a sign of wellness. Food supply is no longer a problem, especially in the urban areas, which is why overconsumption has led to an energy imbalance [124]. The Western diet, consisting of added sugars, refined carbohydrates and saturated fats, is becoming more and more popular in urban China [105]. In 1980, a family planning policy was enacted to limit over-population. Since then many families, especially in urban areas, have had only one child. Grandparents are commonly involved in raising the child and they often retain the traditional idea that adiposity in childhood indicates that the child is strong and healthy. The child is often over-protected by parents and grandparents, and food can be used as a reward and to convey affection [125, 126]. Chinese children in primary school are more likely to be overweight or obese if they are taken care of by their grandparents than by their parents or other adults [125]. Socio-economic changes have also led to a decrease in occupational, transportation [127] and leisure time physical activity [124] over the past two decades. Chinese children are under a lot of pressure to perform well in school, which is why time after school is often spent being sedentary while studying. Structured activities outside school are very rare [128, 129].

2.2.4 Risk factors

There are many factors associated with the risk of obesity in children. The strongest risk factor is parental overweight or obesity. Children growing up with two obese parents run six times the risk of being overweight at age four, compared with children who have parents with

normal weight [130, 131]. Socioeconomic status, often determined with educational level, is another strong risk factor, affecting body composition as early as during the first years of life [132, 133]. In Sweden, infants of parents with low educational levels have higher relative weight at three, six and twelve months of age than infants with highly-educated parents [134]. Socioeconomic status is related to BMI in developing countries as well, but here the association is reversed. As an example, in China, the prevalence of obesity is higher among those with high socio-economic status [105]. Furthermore, living in rural areas versus urban areas plays a role. In Sweden, rates of obesity are higher in rural areas than in urban areas [135]. As with socio-economic status, the opposite is seen in China where overweight and obesity are more prevalent in urban areas [105, 116]. Examples of other risk factors are, family structure [136], ethnicity [135], maternal smoking during pregnancy [137], birth weight [138], and rapid growth in infancy [139].

2.2.5 Tackling childhood obesity

Treatment of obesity is difficult, and the older the child, the poorer treatment results [140]. Primary prevention refers to efforts to avoid disease before it breaks out. Studies have shown that obese children tend to keep their obesity into adulthood [141], which is why primary prevention that target children at increased risk for obesity should be given high priority. Since 2003, the Chinese government has increased the effort to tackle the obesity-problem starting with a release of Guidelines for Prevention and Control of Overweight and Obesity in Chinese Adults. In line with that, Healthy lifestyle initiatives were launched in 2012 with the goal of reducing obesity rates to under 12% in adults and under 8% in children by 2015 [124].

2.2.5.1 The role of physical activity in obesity prevention

It is reasonable to assume that physical activity is important in preventing and curing obesity, since it is highly correlated with energy expenditure. The amount of physical activity needed to balance a high-energy diet is fairly large, however. The amount of energy expended through physical activity is often over-estimated by the individual, leading to a compensatory exaggeration in energy intake [142]. A few studies have found cross-sectional associations between physical activity and BMI in school-age children [143] and adolescents [144], and a low level of total activity have been found to predict the development of overweight and obesity in children and adolescents [123]. The amount needed to achieve these health outcomes, however, is not known. Some argue that obesity could be a driver for inactivity [45], also in children [75] but these results needs to be confirmed in larger-scale longitudinal studies. Nevertheless, obesity is associated with increased risks for various comorbidities that physical activity can prevent and cure. Promoting physical activity among overweight or obese individuals and individuals at high risk for obesity is even more important than promoting it among individuals at low risk or at who are at normal weight [145, 146], also in children [147, 148].

Another important reason for including physical activity in obesity prevention programs is that unhealthy habits have a tendency to cluster [63, 149]. As early as the preschool years, TV-viewing and parental reported sedentary time has been associated with low consumption of fruit and vegetables, high energy intake [150, 151] and drinking sugar-sweetened beverages as well as an increased BMI two years later [152].

2.3 SUMMARY

Physical activity has many positive health consequences in adulthood and childhood, but little is known about levels, patterns and correlates of physical activity in children under the age of three (referred to as “toddlers”). There is also a knowledge-gap in how physical activity behaviors differ among countries and among children at low and high risk for obesity. Increasing this knowledge is of importance for identifying risk groups and tailoring intervention strategies.

3 AIMS

The overall aim is to explore physical activity and possible correlates in toddlers (children aged 1-2.9), at high and low risk of obesity in Sweden and in China.

3.1 SPECIFIC AIMS

To calibrate and cross-validate the Actigraph GT3X+ accelerometer for wrist placement in ambulatory two-year-old children through developing intensity thresholds for sedentary, low- and high-intensity physical activity (*Study I*).

To describe the levels and patterns of physical activity in Swedish two-year-old children and Chinese one- and two-year-old children at high and low risk of obesity (*Studies II-IV*).

To study possible correlates of physical activity and sedentary behavior such as sex, BMI, motor skills and family-related factors in toddlers at low and high risk of obesity (*Studies II-IV*).

To compare physical activity levels and patterns between Swedish and Chinese toddlers at low and high risk of obesity, and their parents; and to examine parental-child physical activity correlations (*Study IV*).

4 METHODS

4.1 STUDY DESIGN AND OUTLINE

Study I is a calibration study aiming at developing and validating intensity thresholds for sedentary, low- and high-intensity physical activity in two-year-old children for the Actigraph GT3X+ accelerometer, worn on the wrist.

Studies II-IV are explorative cross-sectional studies where physical activity levels, patterns and correlates were examined.

An overview of the studies is displayed in Table 2.

4.2 MATERIAL

4.2.1 Calibration study (Study I)

In 2011, a total of 38 children were recruited via four preschools in Stockholm. Ambulatory children aged between 15 and 30 months were included. Data from 26 of the children was used to derive intensity thresholds, data from the remaining twelve children were used for cross-validation of the derived intensity thresholds. The derived intensity thresholds were then applied on a sample of free-living children participating in Early STOPP *Sweden*.

Physical activity data from the first ten high-risk children and the first ten low-risk children recruited were used.

4.2.2 Early STOPP

Early STOPP started as an initiative to investigate the possibility of preventing childhood obesity among a risk-group, based on parental overweight or obesity, of children in Stockholm, Sweden [153]. A parallel project was also started in Wuhan, China. In each country a cohort of families with preschool children are followed for five years, starting when the child is one year old. Children with chronic health problems that are likely to influence dietary habits, physical activity or growth are not included.

The Swedish study, but not the Chinese, includes an intervention component (described below). For this thesis, child and parental data was collected from the baseline visit (child aged one year) in Early STOPP *China* (Study III) and from the follow-up visit (child aged two years) in Early STOPP *Sweden* (Study II and IV) and Early STOPP *China* (Study IV).

Table 2. Description of the studies included.

| | Study I | Study II | Study III | Study IV |
|---|---|--|---|---|
| Aim | <p>To calibrate the Actigraph GT3X+ for wrist placement on ambulatory two-year-old children by developing intensity thresholds for sedentary, low- and high-intensity physical activity.</p> <p>To cross-validate the developed intensity thresholds.</p> <p>To apply the thresholds on a sample of free-living children.</p> | <p>To describe the levels and patterns and study possible correlates of physical activity and sedentary behavior in two-year-old Swedish children.</p> | <p>To describe physical activity levels in one-year-old Chinese children at high and low risk for obesity.</p> <p>To assess the association between child physical activity and sex, BMI and parental physical activity and other parental-related factors.</p> | <p>To compare physical activity patterns in two-year-old Swedish and Chinese children at high and low risk for obesity.</p> <p>To compare parental physical activity levels between countries and to assess correlations in parent-child activity, adjusting for potential confounders.</p> |
| Design | Calibration study | Explorative cross-sectional | Explorative cross-sectional | Explorative cross-sectional |
| Material | <p>38 Swedish children 15-36 months old (26 used for calibration, 12 used for cross-validation).</p> <p>20 Swedish children, aged two ("free-living").</p> | 123 two-year-old Swedish children participating in Early STOPP. | 123 one-year-old Chinese children, 121 mothers and 122 fathers participating in Early STOPP. | 146 two-year-old Swedish children, 145 mothers and 140 fathers and 79 two-year-old Chinese children, 69 mothers and 61 fathers. All participating in Early STOPP. |
| Physical activity variables (main outcome) | Counts-value representing thresholds for sedentary and high-intensity physical activity. | Vertical axis and vector magnitude counts per minute, time (minutes) spent sedentary, in low- and high-intensity physical activity. | Vector magnitude counts per minute. | Vector magnitude counts per minute for children and parents. Time in sedentary, low- and high-intensity physical activity for children. |
| Covariates | Children's Activity Rating Scale. | Sex, BMI, weight status, obesity risk group, motor skills, first born, type of child care, parental education. | Sex, weight and height at birth and at one year; BMI, BMI SDS, ability to walk at one year, obesity risk group, parental age and educational level, household monthly income and living-space, parental BMI and parental physical activity. | Sex, weight and height at birth and at two years, BMI, weight status, obesity risk-group, first born, pregnancy length, age when started walking, type of child care and parental age, weight, height, BMI, educational level and physical activity. |

4.2.2.1 Early STOPP Sweden (Studies I, II and IV)

Recruitment began in 2009 and ended in June 2013. Families were recruited through child health care centers in Stockholm where families with either two overweight parents (BMI 25-29.9 kg/m²) or at least one obese parent (BMI \geq 30 kg/m²) were asked to participate. These high-risk families were allocated to either intervention or control based on cluster randomization of child health care centers. A low-risk group of families with two normal weight (BMI <25 kg/m²) parents were also recruited in the same manner as the high-risk families, representing a reference group.

The Early STOPP *Sweden* intervention includes individual coaching sessions four times per year during the first year and two sessions per year thereafter until the child reaches six years. The sessions are held by trained coaches and cover dietary habits, physical activity and sleep, with focus on habits of the child. In addition, the families in the intervention group receive yearly written information regarding healthy habits for the current age of their child. The control group receives usual care at their child health care centers. They also receive a letter with general health information at baseline and a gift card at each yearly visit. A description of Early STOPP has been published previously [153].

4.2.2.2 Early STOPP China (Studies III and IV)

In 2010, families were recruited at child health care centers in Wuhan, China, in the same manner as in Sweden. Children with two overweight (BMI 24-27.9 kg/m²) or one obese parent (BMI \geq 28 kg/m²) were considered as being at high risk for obesity. Children with at least one normal weight (BMI <24 kg/m²) parent were considered as being at low risk for obesity.

4.3 DATA COLLECTION

4.3.1 Study I

Five preschools in Stockholm were contacted via telephone. The purpose of the study was described to the head of the preschool and if he/she agreed, written descriptions of the procedures were sent via email. All preschools that were contacted agreed to participate, but one was excluded since they had too few children aged 15 to 30 months. The preschool staff handed written study information and forms for consent to parents of children within the right age range.

When at least five parents at one preschool had given consent for their children to participate, two physiotherapists visited the preschool in the morning. The children's weight and height were measured and an accelerometer was attached to the non-dominant wrist with a nylon wrist band. While being video recorded (Canon Legria, FS306, Canon Inc., Tokyo, Japan), a maximum of six children at a time performed three structured activities. While seated, they first watched a cartoon, secondly drew seated by a table and third ran an obstacle course indoors. Each activity continued for at least five minutes. The structured activities were followed by an outdoor session when children were performing optional activities for at least

15 minutes. Start and stop time was registered for all activities using the internal clock of the same computer used to initialize the accelerometers. After the session, accelerometer data was downloaded and synchronized with the video material.

The intensity thresholds thus derived were subsequently applied to physical activity data from 20 children who had worn the accelerometer for one week while participating in Early STOPP *Sweden*. Data from the first ten high-risk and the first ten low-risk children were used.

4.3.2 Studies II, III and IV

Within two months of the child's first and second birthday, families came to the research center at Karolinska University Hospital in Huddinge or Solna, Sweden. In Wuhan, China, families were visited by research assistants in their homes. All involved researchers and research assistants had received training in conducting measurements and data collection. Detailed protocols describing the procedures were also available. Data on child physical activity (Studies II, III and IV) and parental physical activity (Studies III and IV) was assessed with accelerometry for one week before or after the visit. During the visit, both child and parental weight and height were measured. In Sweden, motor skills were assessed with the Hempel test at age two. In connection with the yearly visit, parents filled in questionnaires regarding background and demographic information.

4.4 MEASUREMENTS

4.4.1 Physical activity: Accelerometry (Studies I-IV)

Physical activity was measured with the Actigraph GT3X+ accelerometer (Actigraph, Pensacola, FL, USA). Data was collected at 30 Hz and summarized over 5 seconds for children and 60 seconds for parents. Using the ActiLife software version 6.9, data from the vertical axis and the VM were downloaded and analyzed (Actigraph, Pensacola, FL).

4.4.1.1 Study I

To derive and cross-validate the intensity thresholds, physical activity of the calibration sample was recorded while performing structured activities and during free play. After deriving and validating the derived thresholds, they were applied to data from twenty children participating in Early STOPP *Sweden* who wore the accelerometer for one week at age two. To exclude sleep time, eleven hours of sedentary time was removed, based on estimated sleep time from diaries filled in by parents and from population-data on two-year-olds [91, 154]. Minutes of sedentary time as well as time in low- and high-intensity physical activity was extracted as well as average physical activity, expressed as counts per minute (CPM) based on the vertical axis and the VM.

4.4.1.2 Studies II-IV

In connection with baseline (child aged one year) and the follow-up visit (child aged two years) in Early STOPP *Sweden* and *China*, children and parents wore the monitor on their non-dominant wrist for seven consecutive days. Nighttime sleep was removed by deleting the hours between 8:00 pm and 7:00 am (Study II) since it has been reported that Swedish two-year-old children go to bed between 8:00 and 9:00 pm, and wake up between 7:00 and 8:00 am [154]. Based on sleep diaries, the hours between 9:00 pm and 7:00 am were removed for the Chinese children and the hours between 10:00 pm and 6:00 am for their parents (Study III). In order to enable comparison between countries, the same hours were removed for Swedish children and parents in Study IV. After visual inspection of the data, extreme outlier were removed [155] and a valid day was defined as >100 VM total counts. To be included in Study II, children were required to have at least four days of data, including at least one weekend day [51]. Since no difference in activity outcomes were found between those with ≥ 1 day vs those with ≥ 2 and ≥ 4 days of data, families with at least one parent and the child with physical activity data for at least one day were included in Studies III and IV [156]. For comparison of weekends and weekdays, at least one parent and the child were required to have data on at least one weekday and one weekend day.

Child outcome variables were average physical activity, expressed as CPM for the vertical axis and the VM. Number of step counts (Study II) and time spent in sedentary, low and high intensity physical activity (Studies II and IV) were also assessed. Bouts of activity was determined (Study II), defined as at least five consecutive minutes spent in low or high intensity, respectively. A sedentary bout was defined as lasting for at least 30 minutes. For each bout, one minute outside the intensity range was allowed.

Parental outcome variable was average physical activity, expressed as VM CPM (Study III and IV). Since no wrist-worn cut-points were available for adults, time in intensities could not be determined.



Child with the accelerometer Actigraph GT3X+

4.4.2 Physical activity: CARS (Study I)

A modified version of CARS [99] was used as the criterion measure, allowing physical activity to be categorized into intensity levels. While watching the video material, activity intensity for each child was scored on a five-step scale in five-second intervals. Level 1 represents resting or minor bodily movements; level 2, non-vigorous arm, leg and trunk movements without translocation of the full body weight; level 3, slow translocation of body weight; level 4, moderate translocation of body weight; and level 5, fast or very fast translocation of body weight. A detailed description on how to score was available [99]. Level 1 was considered sedentary, levels 2+3 were considered low intensity, and levels 4+5 high-intensity physical activity. Data from 26 of the 38 children was used to derive intensity thresholds for sedentary and high intensity physical activity. Intensity levels for both the vertical axis and the VM were developed using receiver operating characteristic (ROC) curves. In deriving the threshold for sedentary, only data from watching cartoons and drawing were used. Only data from the obstacle course and the free play sessions were used in deriving the threshold for high intensity. CARS has been calibrated against heart rate and VO_2 consumption in 5-6 year olds and was found to accurately differentiate between intensities [99]. CARS or modified versions have been used in studies to calibrate accelerometers [100-103]. To cross-validate the derived intensity thresholds, the number of minutes spent in different intensities according to the accelerometer data and CARS were compared.

4.4.3 Anthropometry (Studies I-IV)

In Sweden, weight was measured with an electronic scale (Tanita HD-316, Tanita Corp.; Tokyo, Japan) and height with a portable stadiometer. In Early STOPP *China*, weight was measured with an electronic scale (Xiangshan EB9272H) and height with an infant length rod (WD-B, WujinWeighing Co. Ltd) at age one and with a stadiometer (Leicesteeer height measure, Invicta Plastic Co. Ltd) at age two. Parents reported the birth weights and heights of their children.



Measurement of height

4.4.4 Motor skills: The neurological examination technique for toddler-age according to Hempel (Study II)

In the Early STOPP *Sweden* study, motor skills were assessed at age two using the “Neurological examination technique for toddler age” according to Hempel [37], known as the Hempel test. The test is developed for children 18 months to four years of age and takes about 30 minutes to perform. Assessment of fine, gross and fundamental motor skills is performed while the child is video-taped. The test contains seven parts: prehension, sitting, crawling, standing, walking, and test of cranial nerve function and senso-motor function (muscle tone and reflexes). Afterward a rater watches the video footage and scores each item based on a detailed manual. The scored items are then summarized into a Neurological Optimality Score (NOS), on a scale from 0 to 58. No reference values for “low” or “high” NOS are provided, but a previous study showed that children exposed to pre- and post-natal polychlorinated biphenyls and dioxins had a median NOS of 53 [157]. Based on that, children were classified into NOS <53 and ≥53. The inter-rater reliability has been shown to be satisfactory (mean kappa value 0.93). In Early STOPP *Sweden*, the Hempel test was performed by two alternating physiotherapists, who had received one week of training to perform the test by the Dutch research group that developed the test. The test leader gave the child time to adjust to the unfamiliar situation and the parents were always present in the room and were invited to participate if the child wanted. The two physiotherapists scored each test jointly.

4.4.5 Motor skills: Developmental milestone (Studies III-IV)

At age one, parents in Early STOPP *China* answered a question as to whether their child had started walking (yes/no). In the follow-up at age two, parents in both Sweden and China were asked at what age (in months) their child had learnt to walk. This data was used as a proxy for motor skills in Studies III and IV [29].

4.4.6 Socio-economic status: Parental educational level (Studies II-IV), household income and living space (Study III)

In connection with the yearly visits, parents were asked to fill in questionnaires with information about their educational level (nine years of school, twelve years of school, >12 years of school). If at least one parent had at least twelve years of school, the family was considered to have a high educational level. Data on household income (≤3000, 3001-5000, 5001-10000, ≥10001 RMB/month) and living space (in m²) from the Chinese cohort was used in addition (Study III).

4.4.7 Older siblings (Studies II-IV)

Parents reported the number of children in the household and their ages. This information was used to determine whether or not the child was first-born.

4.4.8 Type of child care (Studies II-IV)

Parents reported the type of child care (preschool, full-time or part-time; parents; grandparents; other).

4.5 STATISTICAL ANALYSIS

Table 3. Statistical methods used in the studies.

| | Study I | Study II | Study III | Study IV |
|---|---------|----------|-----------|----------|
| Descriptive statistics | x | x | x | x |
| Independent samples t-test | x | x | x | x |
| ROC ¹ curves | x | | | |
| Spearman's rank correlation | x | | x | |
| Cohen's d | | x | | |
| Analysis of variance (ANOVA) | | x | x | |
| Chi-square test | | | x | x |
| Multivariate regression analysis | | | x | |
| Mann-Whitney's test | | | | x |
| Partial correlation | | | | x |
| Generalized estimating equations models | | | x | x |

¹ROC=receiver operating characteristic

Statistical analysis was performed in SPSS version 22 (SPSS Inc., Chicago, IL) or SAS 9.3 (SAS Institute Inc., Cary, NC). Level of significance was set at $p=0.05$.

4.6 ETHICAL APPROVAL

Ethical permission was obtained from the Stockholm Regional Ethical Review Board (2009/217-31/2, 2009/754-32 and 2011/1147-32) and from the Ethical Committee (IORG0003571) of Tongji Medical College, Huazhong University of Science and Technology in China. The study has been registered in Clinical Trials Registry (clinical trials.gov, ID: ES-2010).

Parents gave their written informed consent prior to inclusion in the calibration- and Early STOPP studies.

5 RESULTS

5.1 STUDY POPULATIONS

A summary of characteristics of included children are displayed in Table 4.

Table 4. Characteristics of the children in the different studies. Mean (SD) or n (%).

| | Study I | | | Study II | Study III | Study IV | |
|-------------------------------|------------------------------|-----------------------------|------------------------------|------------|------------|---------------------------|--------------------------|
| | Calibration sample (n=26) | Validation sample (n=12) | Free-living sample (n=20) | (n=123) | (n=123) | Swedish sample (n=146) | Chinese sample (n=79) |
| Age (months) | 26 (6.0) | 25 (5.6) | 24 (0.7) | 24 (1.2) | 12 (0.3) | 24 (1.2) | 24 (1.2) |
| Boys | 16 (62%) | 6 (50%) | 9 (45%) | 61 (50%) | 75 (61%) | 75 (51%) | 44 (56%) |
| Height (cm) | 89.6 (5.1) | 90.3 (6.2) | 88.8 (2.9) | 87.8 (3.4) | 77.3 (2.8) | 87.9 (3.2) | 89.6 (3.4) |
| Weight (kg) | 13.9 (1.6) | 14.2 (1.8) | 12.8 (1.2) | 13.0 (1.6) | 10.4 (1.1) | 13.1 (1.6) | 13.6 (1.7) |
| BMI ¹ | 17.2 (1.7) | 17.5 (2.5) | 16.3 (1.2) | 16.9 (1.4) | 17.4 (1.5) | 16.9 (1.4) | 16.9 (1.7) |
| Overweight/obese ² | 6 (23%) | 3 (25%) | 0 (0%) | 16 (13%) | | 20 (14%) | 10 (13%) |

¹BMI = Body Mass Index (kg/m²)

²BMI classification according to Cole et al. 2000

Study I consisted of 38 Swedish children, aged 15 to 30 months. Data from 26 of the 38 children were used for calibration (mean age 26 (SD 6.0) months) and twelve were used for cross-validation (mean age 25 (SD 5.6) months). The free-living sample in Study I consisted of 20 children (nine girls), aged two, in Early STOPP *Sweden*.

In Study II, 123 Swedish children remained for analysis after exclusion of 40 children who did not wear the accelerometer and 15 children with less than four days of data or no weekend data (n=2). Of the 123 families, 70% were considered to be high-risk and 30% as low-risk. There were no differences between children who wore and who did not wear the accelerometer, except for a 0.9 kg/m² higher BMI in the children who did not wear the accelerometer.

Out of 299 families recruited to Early STOPP *China*, Study III consisted of 123 families after exclusion of families with incomplete data on parental weight (n=10), either not receiving accelerometers or not using them (n=135), and families where the child and at least one

parent did not wear the monitor (n=31). Of the 123 families, 66 were considered to be high-risk and 57 to be low-risk.

Data from 146 Swedish children, 145 mothers and 140 fathers were available for Study IV. In China the corresponding number were 79 children, 69 mothers and 61 fathers. Of the Swedish families, 73% were considered as having high risk. In China, the corresponding number was 52%.

Since no differences in any physical activity variables were found between children in the control- and intervention groups (Sweden), they were merged and in this thesis are referred to as the high-risk group.

5.2 CALIBRATION OF ACTIGRAPH GT3X+ (STUDY I)

Children were observed for 15 to 36 minutes (29 minutes on average) while performing structured activities and during free play. Mean accelerometer counts differed significantly between intensity categories as assessed with CARS. The counts range per five seconds, together with sensitivity, specificity and area under the curve (AUC) for the vertical axis and the VM are displayed in Table 5. The intensity threshold labelled “Sedentary” refers to the cut-off between sedentary and low intensity physical activity and the threshold labelled “High intensity” refers to the cut-off between low- and high-intensity physical activity.

Table 5. Sensitivity, specificity, area under the curve (AUC) and counts range (5 sec) for sedentary, low- and high-intensity physical activity, respectively. Calibration sample n=26.

| Axis | Activity level | Sensitivity (%) | Specificity (%) | AUC (95% CI) | Counts range (5 s) |
|------|------------------|-----------------|-----------------|------------------|--------------------|
| Y | Sedentary† | 100 | 60.0 | 0.98 (0.95-1.00) | ≤ 89 |
| | Low intensity | | | | 90-439 |
| | High intensity† | 60 | 92 | 0.88 (0.78-0.97) | ≥ 440 |
| VM | Sedentary† | 100 | 60.0 | 0.98 (0.95-1.0) | ≤ 221 |
| | Low intensity | | | | 222-729 |
| | High intensity † | 60 | 92 | 0.90 (0.81-0.98) | ≥ 730 |

†Sedentary from watching cartoons and drawing; high intensity from obstacle course and free play.

The consistency between the CARS score and the accelerometer data, examined by cross-validation, showed a correlation above 0.69 for all intensities. However, the accelerometer overestimated sedentary time, underestimated low-intensity time and overestimated high-intensity time.

The free-living sample had an average of 5.8 (SD 0.6) days of accelerometer data. They spent an average of 384 (SD 70) minutes being sedentary, 307 (SD 46) minutes at low-intensity and 89 (SD 34) minutes at high-intensity per day. Average CPM for the vertical axis and the VM were 1116 (SD 262) and 2920 (SD 671), respectively.

5.3 PHYSICAL ACTIVITY IN TWO-YEAR-OLD SWEDISH AND CHINESE CHILDREN (STUDIES II AND IV)

Mean BMI at age two was 16.9 kg/m² for both Swedish and Chinese children; 14% and 12%, respectively, were overweight or obese in the two countries. In Sweden, 58% of the children were the oldest child, versus 82% of the Chinese children. Almost all Swedish children (97%) attended preschool while three out of four Chinese children were cared for by grandparents. No Chinese children attended preschool. Swedish children started to walk almost one month before the Chinese children. The number of valid days of accelerometer data differed significantly by country ($p<0.05$). Swedish children had a mean number of 6.7 (SD 0.7) valid days compared to the Chinese children, who had 4.8 (SD 2.2) valid days on average.

Levels

Swedish children accumulated an average of 3046 (SD 524) VM CPM in Study II and 2989 (SD 702) VM CPM in study IV, and spent 57%, 34% and 9% of the day respectively in sedentary, at low- and high-intensity (Study IV). They were significantly more active compared with their Chinese counterparts, who had an average of 1997 (SD 899) VM CPM, spent 70% of the day being sedentary and 25% at low- and 5% at high-intensity (Study IV) (Table 6).

Table 6. Physical activity levels (mean (SD) per day) for Swedish and Chinese children at age two (Study IV).

| | Sweden (n=146) | China (n=79) |
|----------------------|---------------------------|-------------------------|
| VM CPM | 2989 (702)* | 1997 (889) |
| Sedentary (min) | 445 (68)* | 545 (99) |
| Low intensity (min) | 261 (49)* | 195 (79) |
| High intensity (min) | 73 (29)* | 40 (26) |

*Significant difference ($p<0.05$) between the countries.

Patterns

Swedish children had an intermittent activity pattern, with short bursts of high-intensity physical activity (Study II). Four children (3%) had at least one bout of high-intensity physical activity lasting at least 5 minutes on a daily average. Almost 80% of the children had a bout of low-intensity physical activity lasting for at least 5 minutes. On average, the children had 2.5 bouts of sustained sedentary, lasting for at least 30 minutes per day (Study II).

The Swedish and Chinese hourly pattern of physical activity during weekdays and weekends are displayed in Figure 1 (Study IV). Weekdays and weekends were almost similar for children in both countries (Studies II and IV). Activity levels differed significantly between Swedish and Chinese children at all times during the day, except at 12 am. Swedish children varied their activity levels more during the day compared to the Chinese children (Study IV).

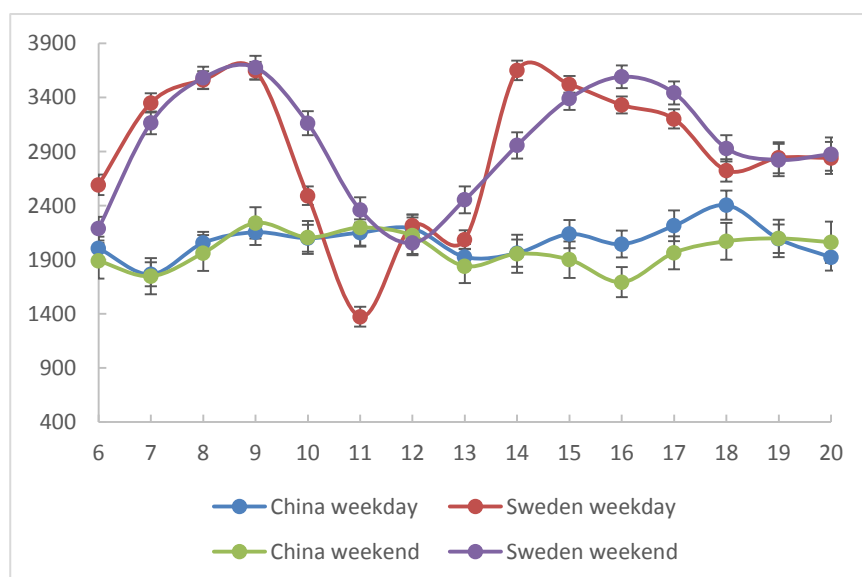


Figure 1. Hourly physical activity levels (mean VM CPM and 95% CI) on weekdays and weekends for Swedish and Chinese two-year-old children (Study IV).

Correlates

Average physical activity (VM CPM) or time spent in sedentary, low-intensity or high-intensity did not differ by sex, BMI, motor skills or any family-related variable (Studies II and IV). Chinese children at high risk of obesity were more active, spent less time being sedentary and 19 more minutes in low- and five more minutes in high-intensity in comparison with children at low risk for obesity ($p=0.05$) (Study IV). In Sweden, children at high and low risk for obesity were equally active (Studies II and IV).

5.4 PHYSICAL ACTIVITY IN ONE-YEAR-OLD CHINESE CHILDREN (STUDY III)

Levels

The children accumulated an average 2078 (510) VM CPM and there were no significant difference between children at high and low risk for obesity ($p=0.06$) or between boys and girls ($p=0.23$).

Patterns

The children had the highest average activity level between 6:00 pm and 8:00 pm and were least active between 2:00 pm and 4:00 pm ($p<0.001$). The physical activity pattern over the day is displayed in Figure 2. Physical activity levels were similar during weekdays and weekend days but children had a higher activity level at 5:00 pm ($p=0.01$) on weekends compared to weekdays.

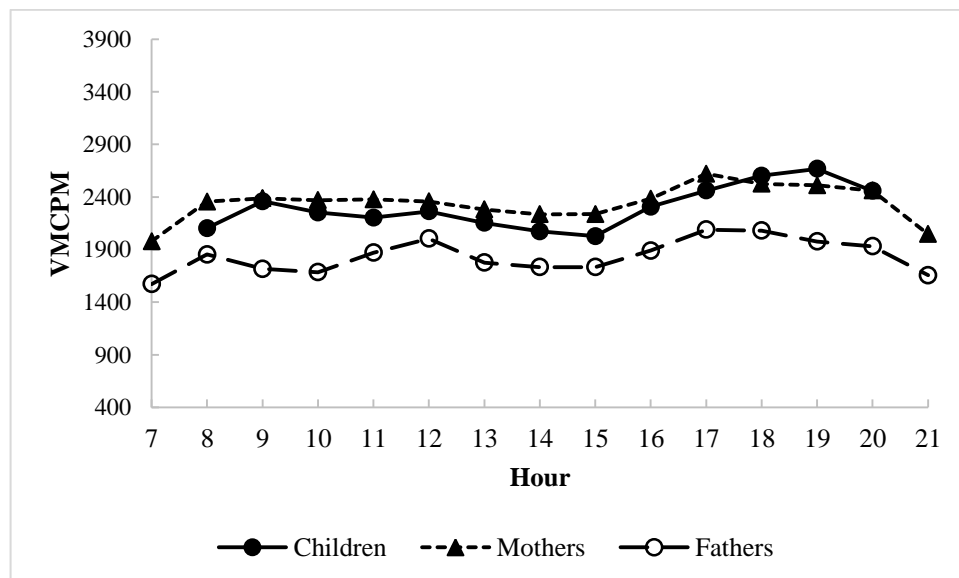


Figure 2. Hourly physical activity pattern of one-year-old Chinese children and parents, averaged over the measured days (Study III).

Correlates

After adjusting for potential confounders, only maternal physical activity was associated with children's physical activity ($p<0.05$, $\beta=0.2$).

5.5 PHYSICAL ACTIVITY IN SWEDISH AND CHINESE PARENTS (STUDIES III AND IV)

Background and physical activity data of Swedish and Chinese parents are displayed in Table 7. Swedish parents were older, taller, heavier, had a higher BMI and more valid days of accelerometer data compared to their Chinese counterparts ($p<0.05$). Swedish parents were

significantly more active than Chinese parents ($p<0.05$). Swedish mothers and fathers accumulated an average 2625 (SD 752) and 2233 (SD 749) VM CPM and Chinese mothers and fathers 2042 (SD 821) and 1588 (SD 754) VM CPM, respectively. Mothers were significantly more active than fathers, both at child age one ($p<0.001$) (China, Study III) and at age two ($p<0.001$) (Sweden and China, Study IV). Physical activity did not differ between weekdays and weekends (Studies III and IV), but Chinese mothers were more active between 3:00 and 5:00 pm ($p<0.05$) on weekends than during the same hours on weekdays (Study III). Chinese fathers were more active between 7:00 and 8:00 am on weekdays compared to weekends ($p<0.001$) (Study III). Parents in the high-risk and the low-risk groups were equally active (Study IV).

Table 7. Descriptive data on parents in Sweden and China (Study IV).

| | Sweden | | China | |
|-------------------------------------|------------------|------------------|-----------------|-----------------|
| | Mother | Father | Mother | Father |
| | Total (n=145) | Total (n=140) | Total (n=69) | Total (n=61) |
| Age (years), mean (SD) | 34.8 (4.7)* | 37.2 (5.5)* | 29.1 (3.6) | 31.6 (4.8) |
| Weight (kg), mean (SD) | 82.3 (20.0)* | 89.4 (15.8)* | 60.8 (10.1) | 79.0 (11.6) |
| Height (cm), mean (SD) | 167.0 (7.1)* | 180.4 (6.4)* | 160.0 (5.1) | 180.4 (6.4) |
| BMI (kg/m ²), mean (SD) | 29.5 (7.0)* | 27.6 (4.8)* | 23.9 (3.6) | 26.4 (3.6) |
| Educational level, n (%) | | | | |
| High | 105 (75) | 102 (75) | 49 (72) | 46 (77) |
| Low | 35 (25) | 34 (25) | 19 (28) | 14 (23) |
| Valid days, mean (SD) | 6.7 (0.9)* | 6.7 (0.9)* | 5.4 (1.8) | 5.6 (1.7) |
| VM CPM, mean (SD) | 2625 (752)* | 2233 (749)* | 2042 (821) | 1588 (754) |

*Significant difference ($p<0.05$) between Sweden and China

5.6 PARENT-CHILD CORRELATIONS IN PHYSICAL ACTIVITY (STUDIES III AND IV)

Sweden

At two-years of age, a positive correlation was found between fathers' and sons' physical activity on weekdays ($p<0.05$, $r=0.49$) and weekends ($p<0.05$, $r=0.37$), adjusted for potential confounders (see Table 2). Father's and daughter's physical activity was not correlated, and mother's physical activity was not correlated with either son's or daughter's physical activity (Study IV).

China

At age one, 14% of the variation in child physical activity was explained by a model containing sex, parental BMI and parental physical activity. Of the variables included, only maternal physical activity was significantly, but weakly, correlated with child physical activity ($p<0.05$, $\beta=0.2$) (Study III). At age two, no parental-child correlation in physical activity was found in China (Study IV).



6 DISCUSSION

6.1 MAIN FINDINGS

Swedish children are more active and have a more variable hourly activity pattern compared with Chinese children at age two. Physical activity patterns are similar during weekdays and weekends, and physical activity levels do not seem to be related to sex, BMI, motor skills or socio-economic status at this age. Paternal activity seems to be important for the activity of Swedish boys at age two. Mothers are more active than fathers and Swedish parents are more active than their Chinese counterparts.

6.2 PHYSICAL ACTIVITY LEVELS AND PATTERNS

This thesis confirms that toddlers (children aged 1 to 2.9) have an intermittent activity pattern with short bursts of high-intensity activity and few sequences with prolonged sedentary time [64]. Objective methods like accelerometry should therefore be the method of choice for this age group, and a frequent sampling rate should be used to capture the intermittent activity pattern. The intensity thresholds developed in this thesis are valid for use in children aged two.

The Swedish children had significantly higher mean activity levels, spent less time being sedentary and more time in low- and high-intensity activities, compared with Chinese children. The Swedish children were physically active at high intensity for an average of 84 minutes per day compared to the Chinese children, who accumulated about 40 minutes of high intensity per day. In previous studies, the reported number of minutes per day in at least moderate intensity varies from 2 to 70 for toddlers and preschoolers [14, 51, 54, 57]. The reason for these large differences can partly be explained by differences in the placement site of the monitor, by the definition of intensity levels, and by the cut-points applied. Thus, comparison with other studies is difficult. In this thesis, the same protocol was used for data collection and analysis in both countries, indicating that differences found are due to other factors discussed below.

It is known that activity levels differ on weekdays and weekends in school-age children [58-60, 68] and variation across days have been found as early as age four [61-63]. We found that activity levels in both Swedish and Chinese children were similar on weekdays and weekends, indicating that differences between weekdays become apparent during the later preschool years.

Among the Swedish children, the highest activity levels occurred during the late morning and late afternoon hours. A similar pattern was found in studies on 19-month-old Australian children with mixed risk [51] and American children aged three, with high risk of obesity [14]. Chinese children varied their hourly activity pattern less than Swedish children and were most active between 6:00 and 8:00 pm, this is later than children in Australia, the United States and the United Kingdom [14, 51, 61, 62]. Children living in western countries tend to have a typical “preschool pattern”, with a decrease in activity around lunch time and

an increase just before and after lunch. In China, the activity levels tend to increase when parents come home from work, around 6:00 pm.

The Chinese children started to walk almost one month later than the Swedish children. Later motor skill development can to some extent explain their lower activity levels. Other important factors to consider are social and cultural differences in day-care and in nurturing. In Sweden and many other western countries, most children attend preschool. In China, on the other hand, most children are cared for by grandparents living in the same household as the child [158]. These differences most certainly affect physical activity levels and patterns and preschool attendance has been linked to increased physical activity [68]. Grandparents play an important role for health-related habits among Chinese children. They have the perception that an obese child is a healthy child [125] and they tend to overfeed [159] and encourage sedentary activities [160]. Involving grandparents in child-care increases the risk of obesity in Chinese children [125]. Grandparents play an important role in Sweden as well, but on the contrary, as support from grandparents seems to decrease the risk for obesity in preschool children [161].

Other possible explanations for the differences in physical activity levels are found within the physical environmental domain. Heat and air-pollution limit time spent outdoors, which in turn has been associated with physical activity [86]. Such environmental factors have been shown to contribute to differences between adolescents in western and developing countries [162]. Like in many large cities in China, air-pollution is heavy in Wuhan and people avoid being outdoors, especially during the afternoon when air-pollution and the heat worsen. Other environmental factors that have been linked with physical activity in children are the walkability and safety of neighborhoods, which differs between countries [15, 65, 67]. Studies of school-aged children have shown that geographical location influences physical activity levels and patterns [163, 164]. For example, adolescents living in Saudi Arabia are significantly less active than British adolescents [165].

Chinese children accumulated about the same average VM CPM at ages one and two. Older children are assumed to accumulate more counts, since they have longer limbs and more developed motor skills that enable them to move around more effectively. One possible explanation is that by age one the child is carried by parents, grandparents or other care givers. A significant part of an infant's physical activity, measured by accelerometry, can be confounded by the caregivers handling the child [92]. Another explanation is that Chinese children are encouraged to be sedentary [160], which is why physical activity levels remain low at age two.

6.3 PHYSICAL ACTIVITY CORRELATES

The socio-ecological framework was used to study possible correlates. Variables within the biological/demographic, socio-cultural and the physical environmental domains were primarily examined, since these variables have been found to be of significance for older children [65] or were assumed to be associated with physical activity at this young age.

It is well known that boys are more active than girls [45, 52, 57] from four years of age, but it has been unclear at what age this difference starts to appear. Our findings indicate that differences between sexes become apparent during the later preschool years. The lack of correlation with BMI is in line with previous studies on preschool-age children with mixed [52] or high risk for obesity [14]. The presence of siblings [68-70] and socio-economic status [63, 67] have also been shown to be unrelated to child physical activity. We show that these factors do not influence physical activity among toddlers in developing countries like China either.

There is evidence suggesting that children with better motor skill competence are more active than children with poorer motor skills at age 5-6 [68] and 8-10 [76]. We found no cross-sectional association between motor skills, either assessed with the Hempel test or with age at which started walking, and physical activity. Swedish children started walking at twelve months of age on average and Chinese children about one month later, which is in line with data from the WHO showing that children usually start walking unassisted around twelve months of age [29]. It is possible that the methods used to assess motor skill development in this thesis were not sensitive enough; this limitation is discussed later in this section.

A somewhat surprising finding was that Chinese children in the high-risk group were more active than children in the low-risk group. One possible explanation is that children in the high-risk group were living in families with higher socio-economic status, with healthier physical activity habits. As mentioned earlier, adiposity is often seen as a sign of wellness in China and obesity is more common among adults (men) with high educational level and income [166, 167]. In Sweden, children at high and low risk for obesity were equally active, which is in line with another study [69].

We found a moderately strong association for paternal, but not maternal, activity and boy's activity in Sweden. Father-son modelling has been found to be stronger than mother-son in a previous meta-analysis [82] and in a review [67]. This was not seen among the Chinese children, but at age one maternal activity was positively, but weakly, correlated with children's activity, thus confirming results from a study on four-year-old children from the United Kingdom [156] and a study on Hispanic preschool children [168]. A study on physical activity in 3.5-year-olds and their overweight/obese mothers, however, found no such association [69]. Whether parental physical activity and child physical activity are associated remains unknown, but it has been suggested that possible pathways are genetics [169], parental support [170], parental role modelling [171-173] or mutual participation [174]. In comparison with Swedish parents, Chinese adults often work long hours. That, together with a heavy work load, limit their ability to be active together with their children [15].

6.4 PHYSICAL ACTIVITY IN PARENTS OF TODDLERS

Since the accelerometer was worn on the wrist, and only average activity (expressed as counts per minute) was used as a measure of outcome for parents in this thesis, comparisons with other studies using another type of monitor and placement site are inappropriate.

Nevertheless, we can conclude that Swedish parents were significantly more active than their Chinese counterparts. During the past decades China has gone through dramatic changes related to economic growth, leading to changes in physical activity behaviors, such as decreased work-related activity [175] and active transportation [45]. As an example, bicycling was the earlier usual way of commuting but in recent decades active travelling, which has been associated with lower risk of obesity and lower BMI in middle-income countries [176], has been replaced by transportation by car or motorcycle. Walkability, an established correlate of physical activity [45], in Asian countries as well, has also decreased in China [177]. The built environment has been found to be of great importance for the physical activity of adults in various countries that differ culturally [178]. Also, parental work demands limit the time for leisure activities [15]. Chinese adults experience great demands at their jobs and work longer hours than Swedish adults in general, factors that are associated with lower activity levels during leisure-time as well [179].

A large cross-sectional study from China showed a clear association between physical activity and BMI, waist circumference and body fat percentages in adults [180], confirming the results from other cross-sectional studies [45, 181, 182]. A causal relationship has, however, not been established. We did not find that parents in low-risk families were more active than parents in high-risk families. Some high-risk families consisted, however, of one obese and one normal weight parent, which is why no conclusion about the association between BMI and physical activity can be drawn from this thesis.

In both countries, mothers were more active than fathers. This is contrary to what has been shown in previous studies [45, 182] also of parents with young children [183]. New parents tend to be less active than adults, at the same age, without children [183, 184]. Becoming a parent is a major life event and physical activity behaviors usually change after having a child, especially for the mother [183], who replaces structured activities with low-intensity house-hold activities. Most studies performed within this research area have used questionnaires or other subjective methods to assess physical activity. Less structured activities are likely to be under-estimated when self-reporting methods are used, which is why mothers possibly have underreported their activity in previous studies. Chinese women have been found to spend more time in low-intensity activities compared with men, when activity levels were assessed with accelerometry [185].

To summarize, except paternal activity in Sweden, no correlates that could explain the variation in physical activity were found in either country. Nevertheless, physical activity levels and patterns differed substantially between countries, among the parents as well. This indicates that country-specific or socio-cultural factors are of greater importance than biological and demographical factors for physical activity among toddlers. Which cultural features contribute to the differences in physical activity between the two countries is still unknown and should be investigated in future studies.

6.5 IS INTERVENING NECESSARY? WHO SHOULD WE TARGET?

The knowledge about the health outcomes of physical activity is limited for infants and toddlers, making it difficult to draw conclusions about if children are physically active enough or not. We found that Swedish children are being active half of their wake time and none of the included factors was found to explain the variability in physical activity. Nevertheless, the differences in activity levels and patterns between children in Sweden and China were significant. This indicates that socio-cultural and environmental factors are of importance and that physical activity levels can be modified.

China is facing a drastic increase in obesity, especially among male toddlers in urban areas [186]. Asian people with a high relative weight are at even greater risk for health complications compared to Westerners. China is the leading country in the world regarding number of individuals with diabetes [187], which is a disease that physical activity can prevent [188] and cure [189]. Given that a low fulfillment rate of health-related physical activity recommendations has been reported among Swedish adults [181, 190, 191], the findings of our study with Chinese parents being even less active is alarming. Physical activity track from early childhood to later childhood [192] and possibly on to adulthood [193, 194] which is why physical activity should be promoted at an early age. Results from this thesis suggest that toddlers and their parents in developing countries like China have a higher need for promoting physical activity than their counterparts in western countries.

6.6 METHODOLOGICAL CONSIDERATIONS

6.6.1 External validity

External validity is linked with generalizability, for who are the results valid? The calibration study was performed on Swedish children, but the derived intensity thresholds were also applied to data on Chinese children. The Chinese children were very similar to the calibration sample regarding height and weight, which is why the derived thresholds should also be valid for that population.

Early STOPP includes families living in Stockholm and Wuhan, which are large cities. They were recruited based on parental BMI, and had a higher educational level than the general population [195, 196]. Although the children included in this thesis were not randomly selected, they are comparable with the general population of two-year-old children in Sweden and urban China as regard body weight and height [197, 198]. Nevertheless, the results should be generalized with caution.

6.6.2 Internal validity

6.6.2.1 Calibration and CARS

Several different sets of intensity thresholds for accelerometer data have been developed for various populations [102, 199-201] but when Early STOPP began, no intensity thresholds for an Actigraph worn on the wrists were available for two-year-old children. The choice of

intensity thresholds obviously has a great impact on the outcomes of physical activity [202]. The difficulties regarding the definition of intensity levels and the fact that toddlers have a movement pattern that differs from older children and adults complicates the accurate classification of physical activity intensity in this age group. What represents low, moderate and vigorous activity at this age is unclear, as well as the health consequences of these intensity levels [203]. Hence, we used the broader terms sedentary, low-intensity and high-intensity to classify the activity levels of toddlers.

Accelerometer counts have been calibrated against measures of energy consumption in older children [201]. In toddlers, such methods are difficult to use, which is why observational methods like CARS have been proposed as the best criterion method [99]. CARS was originally designed for three- to four-year old children and calibrated against oxygen consumption in non-obese five- to six-year olds [99]. An 84% agreement was found between observers when children were observed by eleven different persons over one year for 10-12 hours at a time [99]. CARS has been used in different types of settings (preschool, home, outdoors, restaurants, etc.) and for a variety of observational periods. Modified versions have been used in studies of physical activity in two-year-old children [91, 102]. These studies used different approaches to scoring the intensity levels [91, 102]. The highest intensity observed [91], as well as the weighted average intensity [102] during the predefined time interval, were recorded. The latter approach was used in this thesis, since activities at other intensities occurring during that time interval are masked if the highest intensity level is recorded. As in a previous study [91], standing without moving the hands or arms was classified as sedentary behavior, which can be questionable [8]. This approach was chosen since standing without moving requires very little energy expenditure [204].

As toddlers have intermittent activity patterns (confirmed in Study II), a short epoch length is preferable for detecting short bursts of activity. If data is summarized over a longer period, short bursts of high intensive activity will be obscured by altering periods of rest. We used five second intervals for summarizing accelerometer data, which probably is the shortest epoch length possible when using an observational method.

As in previous calibration studies [100, 102], ROC curve analysis was used to develop the intensity thresholds. By using ROC curves, intensity thresholds are chosen based on sensitivity and specificity. In order to not over estimate activity time, we chose a 100% sensitivity to discriminate sedentary from low intensity activity and a specificity of >90% for the high intensity threshold. Since high sensitivity is chosen at the expense of lower specificity and vice versa, it is possible that time spent in low- and high-intensity physical activity was underestimated in our studies.

Cross-validation was used to validate the derived intensity thresholds, as in a previous study [102]. There are other methods that could have been used, such as the “leave one out” method. We used Spearman rank correlation to measure the strength of association between CARS and the accelerometer data. A measure of agreement could have been more appropriate [205]. We found that the CARS score and accelerometer data corresponded

significantly but the observed bias was quite large, especially for time in high-intensity, which was over estimated by the accelerometer. This is one possible reason for the high amount of time in high intensity observed in Early STOPP, compared to other studies [14, 51, 54, 57].

6.6.2.2 *Accelerometry*

Accelerometers have revolutionized the field of physical activity research. They can accurately measure physical activity among sub-groups such as infants and toddlers where assessment of physical activity is especially challenging, and have been widely used in field settings [91].

Wrist-placement was chosen to enable measurement of sleep [206] and to increase compliance [207]. A wrist worn monitor captures movements performed by the upper limbs. These movements, however, do not require as much energy expenditure as whole-body movements. Thus, a wrist-worn monitor likely overestimate physical activity [208]. A previous study found that a hip-worn monitor generally do better when it comes to identifying activity intensity thresholds, compared with a wrist-worn device [95].

The VM was used in Studies III and IV since it has been found to give a better estimate of physical activity than the vertical axis alone [209], especially when the monitor is worn on the wrist. For parents, only measures of average physical activity were used. Time spent at different intensities could not be determined owing to the lack of intensity thresholds for wrist-worn monitors, but total or average counts have been suggested as a valuable measure regardless of time spent at different intensities [210].

No consensus for data cleaning is available, and the definition of non-wear time varies between studies [203]. It is possible that participants who actually wore the accelerometer were excluded, leading to a lower sample size and increasing the risks for bias [211]. Removing non-wear time by visually inspecting the data is, however, a method with high validity [155]. In Study II, children were required to have at least four days of valid data, in accordance with previous studies [51]. In studies III and IV only one day of data was required. For these studies, the outcome of physical activity was compared for those with ≥ 1 , ≥ 2 and ≥ 4 days of data and found to be equal. It has been suggested that less than three days of accelerometer data is enough in infants and toddlers, since their activity pattern is more consistent between days than in older children [203]. Nevertheless, Swedish children, mothers and fathers had significantly more days of valid accelerometer data than their Chinese counterparts, possibly affecting the results. The fact that Chinese children and parents wore the accelerometer fewer days than their Swedish counterparts is in itself interesting. Future studies could investigate how compliance among this population can be increased.

To have participants wearing the accelerometer for 24 hours per day minimize the risk for participants forgetting to put the monitor back on after removing it for a nap or other reasons [212]. For nighttime sleep, we removed hours based on previous studies of toddler sleep time

[91, 154] and estimation of sleep and wake up time from diaries. It is possible that active time was removed, but it is unlikely that a significant part of the activity of one- and two-year-old children occurs before 7:00 am or after 8:00 pm. Data from studies using different approaches to handling sleep time should be compared with caution.

6.6.2.3 Measurement of motor skills

In the Swedish study, motor skills were assessed with the Hempel test [37]. Which was developed in the Netherlands and aims at detecting minor differences in motor skill development. It is possible, however, that the test was not sensitive enough; almost all children had a NOS score close to the maximum. The test was performed and scored by two physiotherapists who had received one week of training by the research group that developed the test. Nevertheless, it is possible that they were not skilled enough to detect minor neurological delays. Furthermore, the child's motivation, the environment and the contact between test leader and child is of importance for the outcome. To increase the child's motivation, the test leader put effort into talking to the child and giving the child time to adjust to the unfamiliar situation. One or both parents were always present and participated if the child was shy.

Achievement of motor milestones has been used as a measure of motor skills in many studies [213-215]. It is a gross measure of motor skill development; how the child is stimulated and trained to reach the milestone is to a great extent culturally dependent [215]. In addition, since there are various aspects to motor skills, a child who has not started walking can have very well developed fine motor skills that an assessment of motor milestones does not capture.

6.6.2.4 Measurement of body composition

Physical activity was not associated with BMI. Studies have shown that physical activity can affect body composition while BMI remains the same [216]. A small study on Swedish nine- and 14-months-old children found that those with lower amounts of body fat were more active than those with higher amounts of body fat [74]. It is possible that a different measure of body composition, dual-energy X-ray absorptiometry, for example, would have given other results. However, BMI has been shown to be a useful measure for diagnosing obesity during childhood [141].

6.7 STRENGTHS AND LIMITATIONS

6.7.1 Strengths

This is a unique sample of parent-child triads, representing toddlers at high and low risk of obesity, from two culturally different countries, and their parents. Identical protocols were used in both study sites, providing an opportunity to investigate similarities and differences in physical activity and other variables. Physical activity was measured objectively over several days; data was collected at five second intervals, which enabled detection of short bursts of activity. Accelerometer data was collected year-round, which is why the effect of seasonal

variation should have been eliminated. Height and weight were measured objectively by trained research assistants, thereby minimizing the risks for reporting bias. The accelerometer output was calibrated against a conventional observational method and the derived thresholds were tested to ensure their validity.

6.7.2 Limitations

The included children were relatively homogenous with regard to variables like weight, height, motor skills and socio-economic status. It is possible that larger sample-sizes could have detected subtle differences in physical activity that were not discovered in this thesis. Accelerometers have some limitations; the lack of industry standards for translation of accelerometer output makes comparison across studies difficult. New methods for analyzing accelerometer data are being developed but classification into intensity levels is still the most functional approach to handling accelerometer data [5]. Some activities such as bicycling, climbing stairs or carrying loads are underestimated; if the child is being carried by the caregiver, it will falsely be registered as child activity [92]. On the other hand, time for daytime naps was not removed, which is why time spent being sedentary was probably overestimated. Time spent at different intensities could not be determined for the parents, and the absolute output (VM CPM) should not be compared with studies using other types of monitors or in which the monitor was worn on placement sites other than the wrist. The Hempel test and assessment of a motor milestone were used to detect differences in motor skill development. It is possible that these tests were not sensitive enough.

6.8 FUTURE RESEARCH

Future studies should examine the effects of socio-cultural and environmental factors on toddler's physical activity. Also, contextual information about when and under what circumstances physical activity in toddlers and their parents occurs should be explored, as well as the role of grandparents, especially in China. Such studies could provide insight into the reason for the significant differences in physical activity levels and patterns between the two countries, and provide information that could help develop and target physical activity interventions.

No cross-sectional correlates were found in this thesis but some of the variables included may be of importance for physical activity later in childhood. Longitudinal studies such as Early STOPP have the potential to detect determinants of physical activity, dietary habits, sleep, psycho-social health and development of obesity that are occurring already during infancy and toddlerhood.

The role of genetics and epi-genetics was not explored in this thesis. Techniques for studying these factors are being developed and the research field is expanding. There is evidence that physical activity is regulated by genetic factors [217-221], but no studies have focused on toddlers and studies from the Asian countries are lacking.

To overcome problems related to classifying counts values into intensity levels, new ways of analyzing accelerometer data such as pattern recognition and machine learning are being developed. These methods are promising but are not yet user-friendly [222]. I am looking forward at following the development of these techniques.

7 CONCLUSIONS

Two-year-old Swedish children are more active and have a more variable hourly activity pattern compared to Chinese children.

In a Swedish and Chinese population, physical activity patterns are similar during weekdays and weekends and appear not to be related to sex, BMI, motor skills or socio-economic status at this age. Physical activity of Swedish fathers' appears, however, important for the activity of Swedish boys' at age two.

Mothers are more active than fathers, and Swedish parents are more active than their Chinese counterparts.

This indicates that physical environmental or socio-cultural factors influence toddler's physical activity. Future studies need to explore the potential correlates within these domains.

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